PIP-II MEBT Kicker Mechanical Structure

Technical Requirements Specification

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**Document Approval**

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# Purpose

A TRS describes.

# Introduction

The PIP-II MEBT kicker is a part of the MEBT chopping system, which main requirement is to be capable of providing for further acceleration any arbitrary (but pre-determined) bunch pattern out of the 162.5 MHz pulse train exiting the RFQ. This “bunch-by-bunch” selection will be made by two travelling-wave, broadband kickers working in sync and an absorber.

A Functional Requirements Specification [6] and a Technical Requirements Specification [7] for the kicker assembly (i.e. mechanical structure + driver electronics) provide the basis for this TRS.

# Scope

The kicker mechanical structure consists of two identical helical travelling-wave structures with electrodes attached to the helices inside a vacuum vessel. It also includes protection electrodes located on both end of the helices, transmission lines, loads and custom-made feedthroughs.

Guided by the results from electromagnetic simulations, this TRS specifies the parameters for the design of the kicker’s mechanical elements.

# Acronyms

|  |  |
| --- | --- |
| FESHM | Fermilab ES&H Manual |
| FRCM | Fermilab Radiological Control Manual |
| FRS | Functional Requirements Specification |
| L2 | WBS Level 2 |
| L3 | WBS Level 3 |
| LEBT | Low Energy Beam Transport |
| MEBT | Medium Energy Beam Transport |
| OD | Outside Diameter |
| PIP-II | Proton Improvement Plan II Project |
| SCD | System Configuration Document |
| SRF | Superconducting Radio-Frequency |
| TC | Teamcenter |
| TRS | Technical Requirements Specification |
| WBS | Work Breakdown Structure |

# Reference

|  |  |  |
| --- | --- | --- |
| **#** | **Reference** | **Document #** |
| 1 | PIP-II MEBT 200-Ohm kicker EPDM | ED0002198 |
| 2 | Installation and Commissioning (WBS 121.4) System Configuration Document (SCD) | ED000xxxx |
| 3 | [Fermilab Engineering Manual](http://directorate-docdb.fnal.gov/cgi-bin/RetrieveFile?docid=34) | NA |
| 4 | [Fermilab Environmental Safety and Health Manual](http://eshq.fnal.gov/manuals/feshm/) | NA |
| 5 | Fermilab Radiological Control Manual | NA |
| 6 | PIP-II MEBT Kicker Functional Requirements Specification (FRS) | ED0001305 |
| 7 | PIP-II MEBT Kicker Technical Requirements Specification (TRS) | ED0008094 |

# Key Assumptions & Constraints

The length of the vacuum vessel is defined by the periodic structure of the MEBT i.e. 650 mm flange-to-flange between two consecutive transverse focusing stations.

# Requirements

## Helix dimensions

The design of the helical structure (“helix”) is based on the prototype shown in Fig.1. The helix consists of the central copper tube serving as the pulsed voltage signal return, a wire of a rectangular cross section wound around the tube in a helical shape, and electrodes attached to the wire. The position of the wire above the copper tube is determined by 4 ceramic spacers.

At both ends of the helix, the central tube OD is decreased (“stepped-end”) as shown in Fig.2. The cross section of the helical structure (Fig. 3) forms a 200-Ohm microstrip line. The parameters of the helix and transmission line are listed in Table 1 (and in the Annex where US Customary Units were used).



Figure 1. Helical kicker structure (prototype). Note: this helix does not have a stepped-end as shown in Figure 2.



Figure 2. Copper tube, stepped-end and central section. Both tube ends are to step down to a smaller diameter than the central tube section.



Figure 3. Cross section of the helical structure.

Table 1. Dimensions of the helix and transmission line. Notations in *Italic* refer to Figure 3.

|  |  |  |  |
| --- | --- | --- | --- |
| **Item** | **Parameter** | **Value** | **Unit** |
| **Helix** | | | |
| 1 | #13 flat magnet wire dimensions, nominal (*W* × *t*) | 2.667 × 1.067 | mm |
| 2 | Number of helical turns | 47.5 |  |
| 3 | Pitch (*P*). Tolerance of each turn location is with respect to the reference (one end of the ceramic spacer). | 10.46 ±0.05 | mm |
| 4 | Helix wire height above ground in the central section (*h*) | 6.10 ±0.05 | mm |
| 5 | Copper tube central section OD (the helix “ground”) | 28.35 ±0.1 | mm |
| 6 | Central section tube length having the OD value stated in item 4 | 47.615 ±0.03 | cm |
| 7 | Copper tube stepped-end OD at both ends, see item 4 in Section 1.2 and Figure 2 | 20.32 ±0.050 | mm |
| 8 | Helix length measured between wire centers where wire is clamped at both ends (52.5 turns) | 501.4 | mm |
| 9 | Approximate Microstrip wire total length, 52.5 turns | 6.68 | m |
| 10 | Helix diameter, microstrip wire center-to-center | 41.605 | mm |
| 11 | Electrode dimensions (copper) | 7.62 ±0.05 × 20 ±0.05 × 0.508 | mm |
| 12 | Ceramic spacer thickness, (thickness is 1/8 in. nominal) | 3.45 ±0.05 | mm |
| 13 | Ceramic spacer dielectric constant (made out of machinable AlN) | 5.9 ±0.2 |  |
| 14 | Ceramic spacer thermal conductivity, minimum | 50 | W/m/K |
| 15 | Space between facing helix electrode surfaces of the two parallel helices | 16 ±0.5 | mm |
| 16 | Minimum space between helix wire and enclosure surface — top, bottom and sides | 63.5 | mm |
| **200 Ohm Interconnecting Microstrip Transmission Lines** | | | |
| 17 | Signal wire size | #16 solid round wire  (dia. = 1.295 mm) |  |
| 18 | Signal wire height above ground, wire center to ground surface | 8.89 ±0.12 | mm |
| 19 | Ground strip, copper shim stock; width x thickness | 19 ±0.12 × 0.254 | mm |
| 20 | Minimum space between microstrip signal wire and enclosure wall | 25.4 | mm |

## Other mechanical requirements:

1. The two helical structures composing the kicker shall be mounted on one flange and shall be parallel to one another.
   1. Positioning of the parallel helices with respect to each other is determined by the gap dimension between opposing electrode surfaces given in Table 1, item 14.
2. The helix wire shall be wound around the copper tube on a mandrel to form the wire in a uniformly round helix.
3. The two helices shall be wound in opposite directions to each other.
4. The wound helix wire shall pass over the stepped-end for one complete turn at both ends of the copper tube. See Fig. 2.
5. The ceramic spacers holding up the helical wire shall be equally spaced around the copper tube.
6. Each vacuum feedthrough shall be located such that the feedthrough center is lined up with the center of the helix wire at the point perpendicular to where the helix wire is clamped.
7. The interconnecting 200-Ohm microstrip transmission lines, at both ends of the helix, shall connect to the helix such that the transmission line ground is connected to the helix ground tube, and the transmission line wire is connected to the helix wire.
   1. The helix to transmission line wire and ground connections can be made either by soldering or spot welding.
8. The interconnecting 200-Ohm microstrip transmission lines shall have one large-radius curve as it interconnects the helix wire with the vacuum feedthroughs and be perpendicular to the mounting plate as it connects to the feed through.
   1. The height of the signal wire above its ground as given in Table 1, item 17, shall be maintained around the curve.
      1. The radius of curvature radius shall not be less than the value in Table 1, item 19.
9. Electrically insulating supports shall physically hold the transmission signal wire in place very close to the point of connection with the feedthroughs.
   1. The ground of the microstrip line shall be soldered or welded to the feedthrough ground.
   2. The microstrip line signal wire shall connect to a socket that connects to the feedthrough center conductor pin by means of a small, short, stranded wire, soldered or welded.

## Electrical, thermal and vacuum requirements

1. Maximum operational electrode voltage with respect to the ground is 550 V.
2. The helix wire should be clamped with respect to the ground tube at both ends to allow a gradual routing of the connecting 200-Ohm microstrip transmission lines.
   1. Both microstrip lines shall connect to the vacuum feedthroughs located close to their respective helix ends.
3. The first and the last turns of the helix wire shall not have electrodes attached to them.
4. Thermal analyses and tests shall consider that each helix dissipates 6 W of electrical power and 40 W from steady-state beam absorption (assumed to be evenly distributed along the length of the structure).
5. The copper tube shall be water cooled.
6. The structure shall be designed so as to conduct the ~46 W of dissipated power through the ceramic spacers to the copper tube.
   1. The use of vacuum compatible adhesives between the copper wire, ground tube and ceramic spacers is allowable.
7. The kicker structure should not deteriorate from steady-state irradiation from a beam loss of up to 20 A.
   1. The beam loss is assumed to come from the tails of the H- beam
8. All components should be high-vacuum compatible including in the case of steady-state irradiation from the H- beam (item 7 just above).
9. Vacuum without beam should be < 100 nTorr (with active pumping), in accordance with the overall vacuum requirement for the MEBT.

## Protection electrodes

The kicker assembly shall incorporate a pair of electrically isolated plates (protection electrodes a.k.a. masks) for protecting the kicker from accidental beam scraping. The beam current intercepted by the plates will be measured, and the values of the plates currents will be used as an indication of possible beam loss to the helices. The protection electrodes are mounted near the helices, one at each end. Dimensions and resilience to irradiation from beam are given in the MEBT Kicker Assembly TRS [7]. The main requirements are duplicated below for convenience and clarity:

1. The slit height shall be 13 mm.
   1. The slit sides (vertical) from the protection electrodes shall be aligned so that the offset of the assembly gap centerline, (16-13)/2 = 1.5 mm, is within ±0.2 mm.
2. The minimum plate width (horizontal) shall be 40 mm.
3. Each plate should withstand a steady-state heat load from the beam of 40 W.
4. Each plate should withstand an accidental beam loss of up to 20 J.

# Safety Requirements

The system shall abide by all Fermilab ES&H (FESHM) and all Fermilab Radiological Control Manual (FRCM) requirements including but not limited to:

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| --- |
| Pressure and Cryogenic Safety |
| * FESHM Chapter 5031 Pressure Vessels |
| * FESHM Chapter 5031.1 Piping Systems |
| * FESHM Chapter 5031.5 Low Pressure Vessels and Fluid Containment |
| * FESHM Chapter 5031.6 Dressed Niobium SRF Cavity Pressure Safety |
| * FESHM Chapter 5032 Cryogenic System Review |
| * FESHM Chapter 5033 Vacuum Vessel Safety |
| Electrical Safety |
| * FESHM Chapter 9110 Electrical Utilization Equipment Safety |
| * FESHM Chapter 9160 Low Voltage, High Current Power Distribution Systems |
| * FESHM Chapter 9190 Grounding Requirements for Electrical Distribution and Utilization Equipment |
| Radiation Safety |
| * FRCM Chapter 8 ALARA Management of Accelerator Radiation Shielding |
| * FRCM Chapter 10 Radiation Safety Interlock Systems |
| * FRCM Chapter 11 Environmental Radiation Monitoring and Control |
| General Safety |
| * FESHM Chapter 2000 Planning for Safe Operations |

Any changes in the applicability or adherence to these standards and requirements require the approval and authorization of the PIP-II Technical Director or designee.

In addition, the following codes and standards in their latest edition shall be applied to the engineering, design, fabrication, assembly and tests of the given system:

|  |
| --- |
| ASME B31.3 Process Piping |
| ASME Boiler and Pressure Vessel Code (BPVC) |
| CGA S-1.3 Pressure Relief Standards |
| NFPA 70 – National Electrical Code |
| IEC Standards for Electrical Components |

In cases where International Codes and Standards are used the system shall follow FESHM Chapter 2110 Ensuring Equivalent Safety Performance when Using International Codes and Standards and requires the approval and authorization of the PIP-II Technical Director or designee.

Additional Safety Requirements that are not listed in the general list above shall be included in the Requirements table in the Functional Requirements section.

# Annex

Requirements table with dimensions in the US Customary Units system.

|  |  |  |  |
| --- | --- | --- | --- |
| **Item** | **Parameter** | **Value** | **Unit** |
| **Helix** | | | |
| 1 | #13 flat magnet wire dimensions, nom. (*W* × *t*) | .105 × .042 | inches |
| 2 | Number of helical turns | 47.5 |  |
| 3 | Pitch (*P*). Tolerance of each turn location is with respect to the reference (one end of the ceramic spacer). | .412 ±.002 | inches |
| 4 | Helix wire height above ground in the central section (*h*) | .240 ±.002 | inches |
| 5 | Copper tube central section OD (the helix “ground”) | 1.116 ±.003 | inches |
| 6 | Central section tube length having the OD value stated in item 4 | 18.746 ±.01 | inches |
| 7 | Copper tube stepped-end OD at both ends, see item 4 in Section 1.2 and Figure 2 | .800 ±.002 | inches |
| 8 | Helix length measured between wire centers where wire is clamped at both ends (52.5 turns) | 19.74 | inches |
| 9 | Approximate Microstrip wire total length, 52.5 turns | 263 | inches |
| 10 | Helix diameter, microstrip wire center-to-center | 1.638 | inches |
| 11 | Electrode dimensions (copper) | .300 ±.002 × .7874 ±.002 × .020 | inches |
| 12 | Ceramic spacer thickness, (thickness is 1/8 in. nom.) | .136 ±.002 | inches |
| 13 | Ceramic spacer dielectric constant | 5.9 ±.2 |  |
| 14 | Ceramic spacer thermal conductivity, minimum | 50 | W/m/K |
| 15 | Space between facing helix electrode surfaces of the two parallel helices | .630 ±.02 | inches |
| 16 | Minimum space between helix wire and enclosure surface—top, bottom and sides | 2.5 | inches |
| **200 Ohm Interconnecting Microstrip Transmission Lines** | | | |
| 17 | Signal wire size | #16 solid round wire  (dia. = .051 in.) |  |
| 18 | Signal wire height above ground, wire center to ground surface | .350 ±.005 | inches |
| 19 | Ground strip, copper shim stock; width x thickness | .75 ±.01 × .010 | inches |
| 20 | Minimum space between microstrip signal wire and enclosure wall | 1.0 | inches |